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I. BACKGROUND

Butt welding of thick plates is usually accomplished by such welding systems as shielded metal arc welding (SMAW), gas-metal-arc welding (GMAW) or gas tungsten arc welding (GTAW). As indicated in Fig. 1a, a major portion of welding in each of these processes involves the replacement of base metal which has been removed to provide appropriate access for shielding or slag removal. For example, in the case of a 2-inch-thick plate employing a 60° double-vee joint, the amount of sound base metal removed and subsequently replaced by weld metal approximates 1.1 square inches in cross-sectional area; a square butt joint could produce an equivalent joint with less than 0.5 square inches of weld deposit.

As indicated in Fig. 1b, the primary need for a double-vee joint in inert gas arc welding of thick plate is to provide access for ~~the~~ shielding cup in the root area. Welding is accomplished with the wire extended approximately 1/2 inch from the nozzle. A preferable approach to welding would be to use square butt joints with a minimum gap between the edges, such as can be achieved with electron beam welding. Other processes used for square butt joint welding of heavy sections are high density GTAW, submerged arc, electroslag, electrogas and automated narrow-gap GMAW. The narrow-gap welding process is a unique GMAW process which is under development by the Naval Ship Systems Command. The above mentioned automated processes are limited in the repair of defects and welding of inaccessible areas which have to be accomplished by other manual methods.

Due to rising labor and materials costs, a need has arisen for investigating new systems which can more economically fabricate structural components of naval ships. The Extended Electrode Technique (EET) is a unique welding process which offers promise of reducing welding time, welding costs, and quantity of weld metal deposited by 50%. Work performed to date has demonstrated the feasibility of the process for joining quenched and tempered steels under laboratory conditions using manual methods and under shipyard conditions using an automated method . Mechanical tests on weldments indicate that satisfactory large-scale EET weldments can be produced.

The Extended Electrode Technique described in the next section was developed to achieve the advantages of close butt welding and to complement the automated narrow-gap process.

II. EXTENDED ELECTRODE TECHNIQUE

The Extended Electrode Technique illustrated in Fig. 2 utilizes square butt joints with a nominal 1/4- to 3/8-inch gap opening. Wire and gas are fed through standard GMAW semi-automatic welding equipment into the center of the gap. The technique can be used in either the manual or automated mode with wire extensions beyond the contact tube of as much as 2 inches The major differences between the Extended Electrode Technique and the previously mentioned automated narrow-gap welding process are noted in Table I.

Gas Shielding

The purpose of the gas mixtures in EET welding is to protect the molten filler wire tip from atmospheric contamination and to produce an arc that is controllable at 2-inch depths with optimum penetration. Shielding gas used in the process is directed down the center of the groove and also over the surface of the surrounding plate by the two separate shielding systems illustrated in Fig. 2. The inner shielding gas protects the bare wire and the molten puddle in the bottom of the groove; the external shielding device prevents air aspiration into the inner shield column by flooding the plate surface with an inert gas.

The external gas shielding mixture which was used throughout the investigation is a mixture of 98% argon and 2% oxygen. When this mixture, which is normally used to weld ferrous materials, is employed as an inner shielding gas deep in the groove in EET welding, an erratic semispray arc is produced. This arc plays against the sidewalls without reaching the bottom of the weldment, resulting in a porous honeycomb-type weld. The addition of helium (He) to the Ar+2% O_2 gas tends to transform the arc characteristic from an erratic semispray mode to an unstable globular mode. This arc is hotter, due to the higher ionization potential of He, but like the Ar+2% O_2, it also fails to produce a stable arc at the bottom of the groove. Addition of carbon dioxide (CO_2) to the Ar+O_2+He gas in moderate amounts (5% to 15%) tends to stabilize the arc in a globular-type transfer mode which permits welding of up to 2-inch depths. The CO_2 addition reduces the surface tension and gives good wetting characteristics.

Due to the oxidizing potential of CO_2 gas (normally equivalent to Ar+10% O_2), a mixture devoid of O_2 gas was attempted in a further effort to optimize the shielding gas. Mixtures with 3:1 and 1:1 ratios of helium to argon with 5% to 8% CO_2 were prepared. The arc produced by these gas mixtures was similar in characteristics to those obtained with the Ar+He+CO_2+O_2 gas noted above but appeared narrower in width. This narrowing of the arc can cause lack of fusion problems in EET welding if the joint opening is too large. It is therefore considered that the elimination of oxygen from the shielding gas mixture makes a narrower joint opening (3/8-inch) more practical, especially if the process is automated without oscillation of the welding torch.

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Arc Characteristics

Stable arcs with good deposition characteristics are obtained without the use of superimposed travel guides or electrical controls, other than what would normally be used in conventional manual GMAW welding. The arc transfer at the root, which is shown in Fig. 3, is of the globular type. The tendency for spray transfer increases as the length of the electrode extension decreases. In the case of 2-inch-thick material, the globular transfer changes to a spray transfer mode at approximately mid-thickness due to the I^2R heating of the electrode.

III. EET Welding of HY-80 Steel

The quenched and tempered HY-80 steel which was chosen as the base plate material has mechanical properties and composition as shown in Table II.

Small scale mechanical tests performed on the weldments consisted of the following:

1. All-weld tensile properties.
2. Transverse-weld tensile properties.
3. Charpy V-notch properties (Transverse weld).
4. Side bends for ductility.

Nondestructive tests which were performed include:

1. Radiography
2. Ultrasonic
3. Macro examination.

Five different diameter electrodes were tested, the smallest being 0.035-inch and the largest 0.092-inch. Attempts to weld with the 0.035- and 0.045-inch-diameter electrodes (specimens V-1 and V-2) were unsuccessful due to excessive heat buildup in the extended portion of the wire. When the small diameter wires (0.035- and 0.045-inch) made contact with the plate the wire would glow and burn off. Attempts to lower the wire feed rates and amperages did not produce desired welding conditions, and further tests using the small diameter wires in the flat position were discontinued.

The 0.062-inch-diameter wire has performed in a satisfactory manner. The parameters developed for all wires are shown in Table III. The parameters developed with the 0.078- and 0.092-inch-diameter electrodes were considerably different from those for the 0.062-inch wire. Higher currents, in the range of 350 to 450 amperes, were generally necessary to obtain the same arc conditions with the larger wires (0.078- and 0.092-inch) as were obtained with the smaller 0.062-inch wire.

Table IV gives results of the mechanical tests performed on welds with parameters described in Table III. With only a very minor exception (CVN 46 ft/lbs at -60° F) in specimen V-5, both types of filler wires, AX90 and MI88, performed satisfactorily with respect to usability and mechanical properties. The effect of filler wire diameter on Charpy V-notch values while holding the other parameters, such as travel speed, amperage and voltage, almost constant is shown in Fig. 4. The 0.062-inch-diameter wire yielded the highest room temperature Charpy V-notch (CVN) values. Travel speeds noted in Tables III and Fig. 5 appear to significantly affect the CVN values; the slower speed giving higher CVN values than the faster speed. However, the yield strength of these weldments were not significantly affected. Little difference was observed between the yield strengths of the welds using higher travel speeds with the same type and diameter filler wire.

Deposition Rate Affected by I^2R Heating

Electrode extension to a 2-inch depth is very pronounced on the amount of metal deposited in the weldment. As the length of electrode from the contact tip to the work piece is increased, the rate of metal deposition increases. This phenomenon occurs because of resistance heating (I^2R) of the extended portion of the electrode, i.e., the I^2R effect preheats the electrode, facilitating melting and thereby increasing the deposition rate. Fig. 6 shows the effect of the electrode extension on melting rate for various conditions of welding current, shielding gas and gas temperature[1]. Heating the shielding gas increases the melting (and deposition) rate, while changing the shielding gas has relatively little effect on melting rate.

To determine whether I^2R heating had any effects on the properties of weldments, a standard double-vee, explosion-bulge weldment was fabricated with an electrode extension maintained equal to that used for the root pass of a square butt EET weldment.

The all-weld yield strength and Charpy V-notch properties (Table V) of the standard double-vee EET weldment were generally 10% to 30% higher than those of the square butt EET weldment. Bend test, yield strength, and toughness (Charpy V-notch at 0° F) results from both weldments were satisfactory. The transverse weld tensile properties were the same for both weldments. The explosion bulge performance of both weldments was considered satisfactory in accordance with specifications.[2] Both weldments sustained a reduction in thickness greater than 16%. In comparing the results of the two test plates, the square butt EET weldment had a greater reduction in thickness and a lesser degree of cracking on the fifth shot than did the standard double-vee EET weldment. Results of this test and other explosion bulge tests previously reported [3] indicate that the high reduction in thickness attained in narrow, square butt weldments may be due to the type of joint configuration used in welding. However, it is apparent that the I^2R heating of the extended electrode does not have a direct effect on the explosion bulge performance of EET weldments.

EET Under Shipyard Conditions

To establish the feasibility of making EET welds under field conditions, a production facility was contracted to produce an automated EET weldment under field conditions. Preparation procedures are shown in Table VI. Conventional GMAW semi-automatic spray welding equipment was used with a Linde CM-37 automated carriage for positioning the GMAW gun. After the initial side was welded, the backing strap beneath the weld was arc gouged and ground to a 1/8-inch depth below the surface of the plate and manually rewelded with a 5/32-inch-diameter E11018 SMAW electrode. The parameters and bead sequence used for the EET welding of the 72-inch-long plate are shown in Table VII. Fig. 7 shows the satisfactory results of the explosion bulge test and other mechanical properties of the weldment prepared under shipyard conditions.

It is concluded that satisfactory EET welds can be made in large sections under shipyard conditions by the automated EET procedure.

IV. COMPARISON OF EET AND CONVENTIONAL GMAW TECHNIQUES

Direct comparison was also made between weldments using EET and conventional GMAW processes using the material shown previously in Table II.

Results of tensile, Charpy V-notch and side bend tests are shown in Table VIII along with values for comparable conventional GMAW welds made with the same type wire and plate. Typical hardness values for EET welds are shown in Fig. 8. EET weld yield and tensile strengths obtained were approximately 15% higher and Charpy values lower than those using the same type filler wire and conventional GMAW processes.

Explosion bulge tests of conventional GMAW weldments with HY-80 steel normally attain 16% to 20% reduction in thickness. Explosion bulge tests of EET weldments have achieved reduction in thickness of over 20%. These results have been consistently obtained with weldments prepared by the Extended Electrode Technique and are considered to be the upper quality scale of explosion bulge performance for materials of this type. Soundness of the EET weldments determined by nondestructive testing was comparable to welds produced by manual GMAW processes.

V. ADVANTAGES OF EET

In summary, the more significant advantages of the Extended Electrode Technique over other conventional GMAW techniques are shown in Table IX. These include:

- Decreased Distortion - Weldment distortion is reduced by the minimal amount of weld metal deposited.

- Reduced Plate Preparation - In a double-vee joint normally used in thick sections, five flame cutting operations are required. One cut to square the edges and the remaining four to prepare the desired bevels. In addition, each beveled side has to be ground clean to permit a sound weld. In using the EET technique only one flame cutting and two grinding operations are necessary.

- Minimum Amount of Arc Time and Weld Metal - Due to the reduced number of passes, the amount of weld metal and arc time is reduced by 50%.

- Versatility - The technique can be used manually, where it offers the advantages of conventional GMAW systems; and can be useful for short runs or in confined spaces. It also can be readily automated.

- When used as a manual system the EET technique becomes a useful repair tool. Comparative repairs with other techniques require the removal and redeposition of substantially large quantities of weld metal in a "Vee" or "U" type joint configuration.

VI. LIMITATIONS OF EET

• It should be recognized that the Extended Electrode Technique is in a state of development and not a completed production tool. Limited field tests under production conditions have been promising; however, the results indicate that additional field tests will be required for modifications that will transform the technique from a laboratory development to a useful production tool.

• At the present state of development, the Extended Electrode Technique has only been used for thicknesses of 2 inches or less. Applicability to greater thicknesses has not been explored. Accordingly, it is hoped that further work will enable the process to be utilized in thicker sections.

• Work to date has been limited to ferrous materials. It is anticipated that applications relative to nonferrous materials such as aluminum, copper nickel and titanium alloys may be feasible.

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ACKNOWLEDGMENT

The authors gratefully acknowledge the Naval Ship Systems Command, Mr. B. B. Rosenbaum (SHIPS 03422), for sponsorship of the program on which this paper was based.

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REFERENCES

1. C. E. Jackson and J. S. Clark, "Study of the Extended Electrode Technique for Welding Ship Structures," Ohio State University Report (Department of Welding Engineering), in progress

2. NAVSHIPS 0900-005-5000, "Standard Procedures for Preproduction Testing Materials by the Explosion Bulge Test," November 1965.

3. A. Pollack, "Narrow-Gap Welds in 2-Inch HY-80 Steel," NASL Project 9300-1, Technical Memorandum No. 12, 7 August 1964.

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Table I

DIFFERENCES IN TECHNIQUES

Criteria	Extended Electrode Technique	Narrow Gap Process
1. Extended Contact Tube	Not Required	Required
2. Wire Straightner	Optional	Required
3. Special Equipment	Not Required	Required
4. Wire Diameter Range	0.062" to 0.092"	0.035" to 0.045"
5. Non-automated (Manual) Feasibility	Yes	No

Table II

HY-80 BASE PLATE PROPERTIES

Chemical Analysis		Mechanical Properties	
Element	Percent	Longitudinal/Transverse	
C	0.16	Yield Strength, ksi	83/83
Mn	0.34	Tensile Strength, ksi	99/100
Si	0.30	Elongation, %	30/26
P	0.006	Reduction in Area %	79/73
S	0.012	Charpy V-notch	
Ni	2.40	(Average ft-lb) -60^{o} F	96/117
Mo	1.25		
Cr	1.47		
V	0.006		
Ti	0.006		

Table III
Parameters for EET Welding

Joint Design - Square Butt
Edge Preparation - Ground (after flame cutting)
Position - Flat

Polarity - Direct Current, Reverse
Preheat Temperature 200° - 300° F

	Specimen Code									
	v-1	v-2	v-3	v-4	v-5	v-6	v-7	v-8	v-9	v-11
Filler Wire Type	AX90	AX90	AX90	MI88	AX90	MI88	MI88	MI88	MI88	AX90
Filler Wire Size (inches)	0.035	0.045	0.062	0.092	0.092	0.062	0.062	0.092	0.078	0.062
Gas Mixture (internal shielding)	(1)	(1)	(1)	(1)	(1)	(2)	(2)	(2)	(2)	(4)
Gas Mixture (external shielding)	(5)	(5)	(5)	(5)	(5)	(5)	(5)	(5)	(5)	-
Gas Flow, cfh (internal/external)	110/ 100	110/ 100	100/ 100	120/ 100	120/ 100	100/ 100	100/ 100	100/ 100	100/ 100	150
Wire Feed, ipm	150-300	150-300	350	145	160	300	300	300	300	350
Travel Speed, ipm	(6)	(6)	14	12	12	14	16	13	15	13
Range, amperes	200	250	280-360	400-460	360-450	280-330	290-310	350-410	330-360	280-380
Range, volts	22	24	30-39	32-39	34-40	27-32	27-28	24-32	24-32	28-35
Interpass Temperature Maximum, ° F	200	200	250	260	240	250	250	250	250	260
Number of Passes	(6)	(6)	15	12	12	10	10	10	12	11

(1) 46% (Argon+2% Oxygen) +46% Helium + 8% Carbon Dioxide
(2) 25% Argon+70% Helium + 5% Carbon Dioxide
(3) 46% Argon+46% Helium + 8% Carbon Dioxide
(4) 98% Helium+2% Oxygen
(5) 98% Argon+2% Oxygen
(6) Weldments aborted

cfh - cubic feet per hour
ipm - inches per minute

Table IV
Mechanical Properties of EET Weldments

Code	Tensile Type	Yield Strength ksi	Tensile Strength ksi	Elongation, %	Reduction in Area %	Fracture	Side Bend Test	Charpy V-Notch (average ft-lb)(1) °F -60°	0°	+30°	Room Temp	Wire Types
V-3	Transverse weld .505	80.9/ 81.6	96.8/ 97.7	18.0/ 18.5	66.2/ 68.7	Base/ Base	(3)	53	80	93	104	0.062 AX90
V-3	All weld .252	110.1/ 113.6	129.8/ 126.3	20.0/ 20.0	63.5/ 63.0	-	-	-	-	-	-	0.062 AX90
V-4	Transverse weld .505	82.7/ 84.1	99.0/ 100.8	18.0/ 17.0	63.1/ 65.9	Base/ Base	(3)	62	84	102	102	0.092 MI88
V-4	All weld .252	108.4/ 107.6	123.3/ 118.7	19.0/ 17.0	70.2/ 65.2	-	-	-	-	-	-	0.092 MI88
V-5	Transverse weld .505	84.3/ 82.4	99.9/ 98.7	18.0/ 17.0	68.5/ 63.6	Base/ Base	(3)	46(2)	71	82	93	0.092 AX90
V-5	All weld .252	107.2/ 110.5	121.2/ 124.2	20.0/ 15.0	62.8/ 29.4	-	-	-	-	-	-	0.092 AX90
V-6	Transverse weld .505	82.6/ 89.0	99.0/ 99.0	20.0/ 19.0	67.6/ 66.5	Base/ Base	(3)	64	76	97	97	0.062 MI88
V-6	All weld .252	107.9/ 115.7	116.5/ 122.7	16.0/ 17.0	56.0/ 57.7	-	-	-	-	-	-	0.062 MI88
V-7	Transverse weld .505	82.5/ 86.3	99.0/ 102.5	18.0/ 18.0	65.7/ 66.3	Base/ Base	(3)	52	75	78	83	0.062 MI88
V-7	All weld .252	106.0/ 108.0	119.2/ 117.2	15.1/ 15.6(2)	51.5/ 56.5	-	-	-	-	-	-	0.062 MI88
V-8	Transverse weld .505	81.2/ 80.4	98.4/ 97.9	19.0/ 19.0	63.4/ 67.9	Base/ Base	(3)	54	77	77	77	0.092 MI88
V-8	All weld .252	101.5/ 107.1	114.8/ 118.8	18.0/ 20.0	54.1/ 68.9	-	-	-	-	-	-	0.092 MI88
V-9	Transverse weld .505	86.4/ 84.7	105.8/ 99.5	18.8/ 19.5	67.3/ 64.9	Base/ Base	(3)	55	62	63	64	0.078 MI88
V-9	All weld .252	118.5/ 114.7	136.5/ 131.4	16.0/ 17.0	40.0/ 56.0	-	-	-	-	-	-	0.078 MI88
V-11	All weld .252	87.7/ 103.0	100.7/ 113.1	22.0/ 18.0	68.5/ 64.5	-	(4)	56	79	80	84	0.062 AX90

(1) Average of four specimens through thickness.
(2) Lower than required by MIL-E-23765/2 (100S).
(3) Two of two specimens passed 2T bend test.
(4) Not tested due to lack of material.

Table V
Results of Mechanical Property Tests
Square Butt EET Weldment vs Standard Double Vee Weldment

Plate Code	Tensile Type	YS, ksi	TS, ksi	Elongation, %	RA, %	Fracture Location
			Tensile Test Results			
466	0.505 Transverse Weld	84.5/ 82.5	100.0/ 98.5	18.0/ 17.0	68.5/ 63.5	Base Metal/ Base Metal
(Square Butt EET)	0.252 All Weld	96.5/ 102.5	129.5/ 123.0	17.0/ 21.0	55.0/ 65.5	- -
541	0.505 Transverse Weld	83.5/ 83.5	105/ 106.5	16.5/ 16.5	67.5/ 65.5	Base Metal/ Base Metal
(Standard Double V EET)	0.252 All Weld	111.0/ 126.5	121.0/ 132.5	21.0/ 21.0	65.5/ 67.5	- -

Charpy V-Notch Test Results
(Average ft-lb -4 Specimens Through Thickness)

Temperature (° F)	Plate 466	Plate 541
-60	45[1]	67
0	71	86
+30	81	90
RT	93	90

Side Bend Test Results

	No. of Specimens Passing 2T
Plate Code 466	2 of 2
Plate Code 541	2 of 2

[1] Lower than the 50 ft-lb required by specification MIL-E-23715/2 (SHIPS).
YS = yield strength, TS = tensile strength; RA = reduction in area

Table VI

PREPARATION PROCEDURES FOR EET WELDING

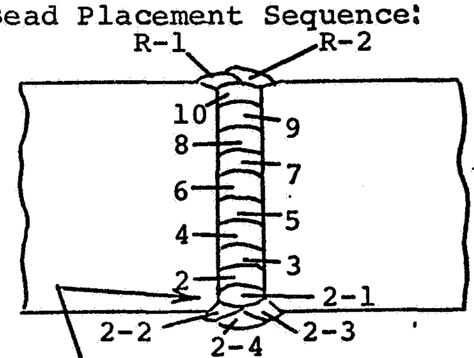
Size of Plate (in.)	- 72x30x2
Joint Design	- Square Butt
Edge Preparation	- Ground (After Flame Cut)
Welding Position	- Flat
Polarity	- Direct Current, Reverse
Filler Wire Diameter	- 0.062-Inch Airco AX90 (Passes 1 to 9, R1 and R2) - 0.157-Inch Airco 11018 (Passes 2-1 to 2-4)
Preheat Temperature °F	- 150 Minimum
Interpass Temperature °F	- 300 Maximum
Welding Equipment	- Linde CM-37 Carriage - Linde SEH-3 Wire Feed Motor and Control - Linde ST-5 Gun

Table VII

BEAD SEQUENCE AND PARAMETERS

Bead No.(1)	1	2	3	4	5	6	7	8	9	10	R-1	R-2	2-1	2-2	2-3	2-4
Amperes, Avg.	285	290	320	340	360	360	370	380	370	370	300	300	185	185	185	185
Volts, Avg.	40	37	37	35	34	33	32	32	31	30	29	29	24	24	24	24
Travel Speed, inch per min.	13	13	13	13	13	13	13	13	13	13	13	13	5.9	9.1	7.6	10.3
Gas Mixture CODE	(2)	(2)	(2)	(3)	(3)	(4)	(4)	(4)	(4)	(4)	(4)	(4)	-	-	-	-
Joules (K joules per inch)	49	50	55	55	53	55	54	55	53	51	39	39	48	30	35	26

(1) Bead Placement Sequence:



Bead No. 1 removed by carbon arc back gouging

(2) 46% (Ar+2% O_2) + 46% (He) + 8% CO_2 at 130 cu-ft. per hr.

(3) 50% (Ar+2% O_2) + 50% (He) at 120 cu-ft. per hr.

(4) 50 cu-ft. per hr. (Ar + 2% O_2), no external shield

MECHANICAL PROPERTIES OF CONVENTIONAL GMAW WELDMENTS vs WELDMENTS PREPARED USING EXTENDED ELECTRODE TECHNIQUE

	EXTENDED ELECTRODE TECHNIQUES		CONVENTIONAL GMA	
	0.062'' DIA. WIRE	0.092'' DIA. WIRE	0.062'' DIA. WIRE	0.092'' DIA. WIRE
YIELD STRENGTH, KSI	113.6	107.2	99	96
TENSILE STRENGTH, KSI	126.3	121.2	108	107
ELONGATION, %	20.0	20.0	23	21
REDUCTION IN AREA, %	63.0	62.8	68	65
CHARPY 'V' NOTCH (FT-LBS)				
-60°	52	54	77	73
0°	80	71	110	101
-30°	92	82	130	110
RT	104	93	130	121
SIDE BEND TEST	ACCEPTABLE	ACCEPTABLE	ACCEPTABLE	ACCEPTABLE

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Table VIII

WELDING R & D

COMPARATIVE DATA: CONVENTIONAL vs EET WELDING

CRITERION	CONVENTIONAL	EET
DISTORTION	APPRECIABLE	MINIMAL
FLAME CUTS PER JOINT GROUND SURFACES PER JOINT	5 4	1 2
ARC TIME,* min. (per ft. weldment)	30	12
VOLUME OF WELD METAL,* in.^{3} (per ft.)	24	12
YIELD STRENGTH, ksi } HY 80 CVN at 30° F, ft.–lb. } HY 80	100 100	110 93

*BASED ON 2–in. THICK WELDMENTS

Table IX

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FIGURE CAPTIONS

1. Double-Vee Joint Required to Provide Access for Shielding Cup in Root Area in Inert Gas Arc Welding of Thick Plate.
2. Arrangement for Extended Electrode Technique Welding of Thick Plate.
3. Globule Formation of EET Welding
    a. Globule Has Fallen and Formation Beginning
    b. Globule Half grown
    c. Globule Grown Almost Ready to Fall
    d. Globule Has Fallen and in Contact with Plate.
4. Effect of Diameter of Filler Wire on Charpy V-Notch Tests with Other Parameters Held Approximately Constant (MI88 Wire, 25% Ar+70% He+5% CO_2 Internal Shielding gas).
5. Effect of Travel Speed on Charpy V-Notch Tests with Other Parameters Held Approximately Constant (MI88, 0.062-Inch Diameter Wire, 25% Ar+70% He 5%+CO_2 Internal Shielding Gas).
6. Melting Rate Versus Electrode Extension.
7. Results of Shipyard Implementation of EET Welding.
8. Typical Hardness Values of EET Welds (Values in R_c).

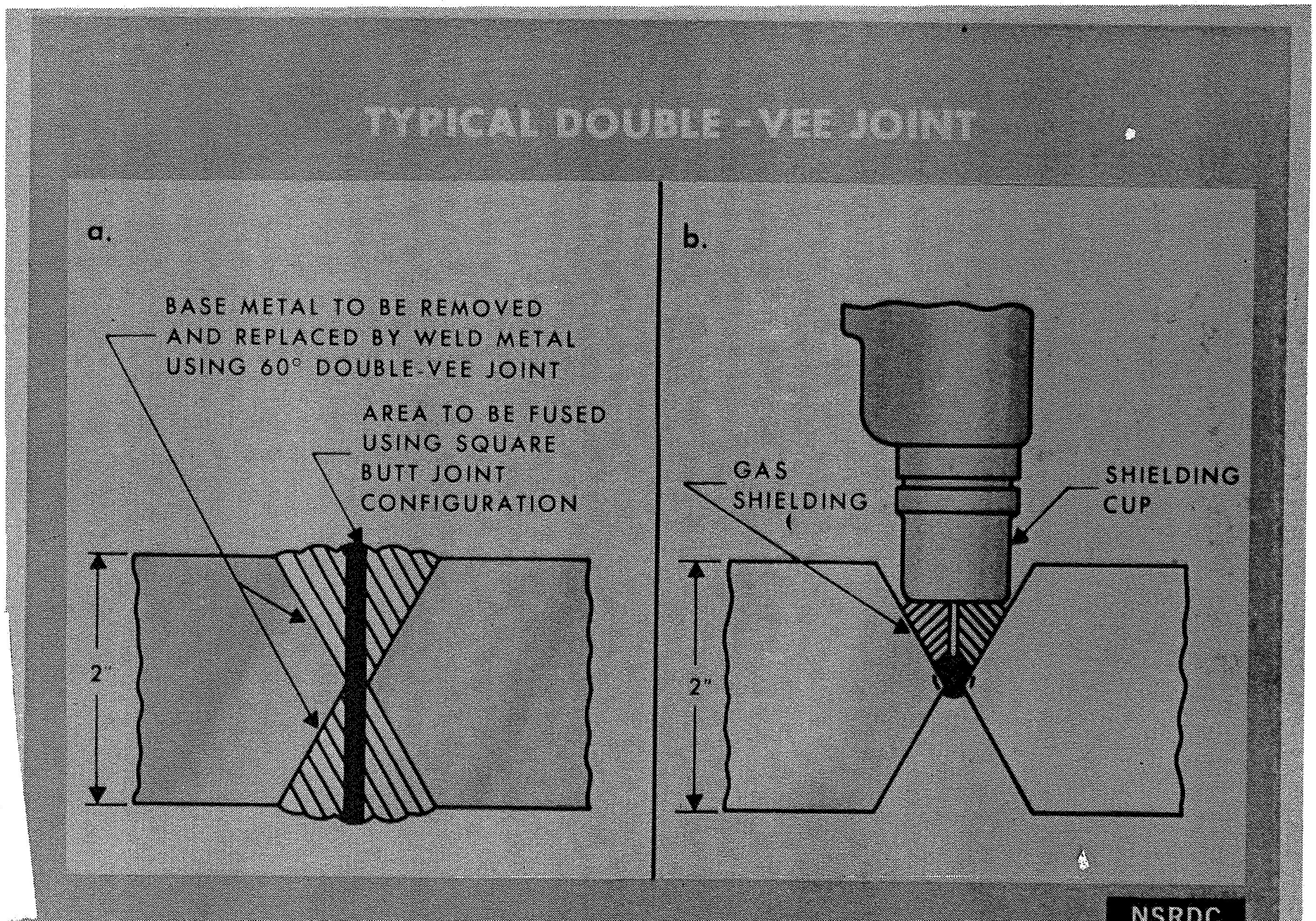
TYPICAL DOUBLE - VEE JOINT
a.
BASE METAL TO BE REMOVED
AND REPLACED BY WELD METAL
USING 60° DOUBLE-VEE JOINT
AREA TO BE FUSED
USING SQUARE
BUTT JOINT
CONFIGURATION
2"
b.
GAS
SHIELDING
SHIELDING
CUP
2"
NSRDC

Figure 1

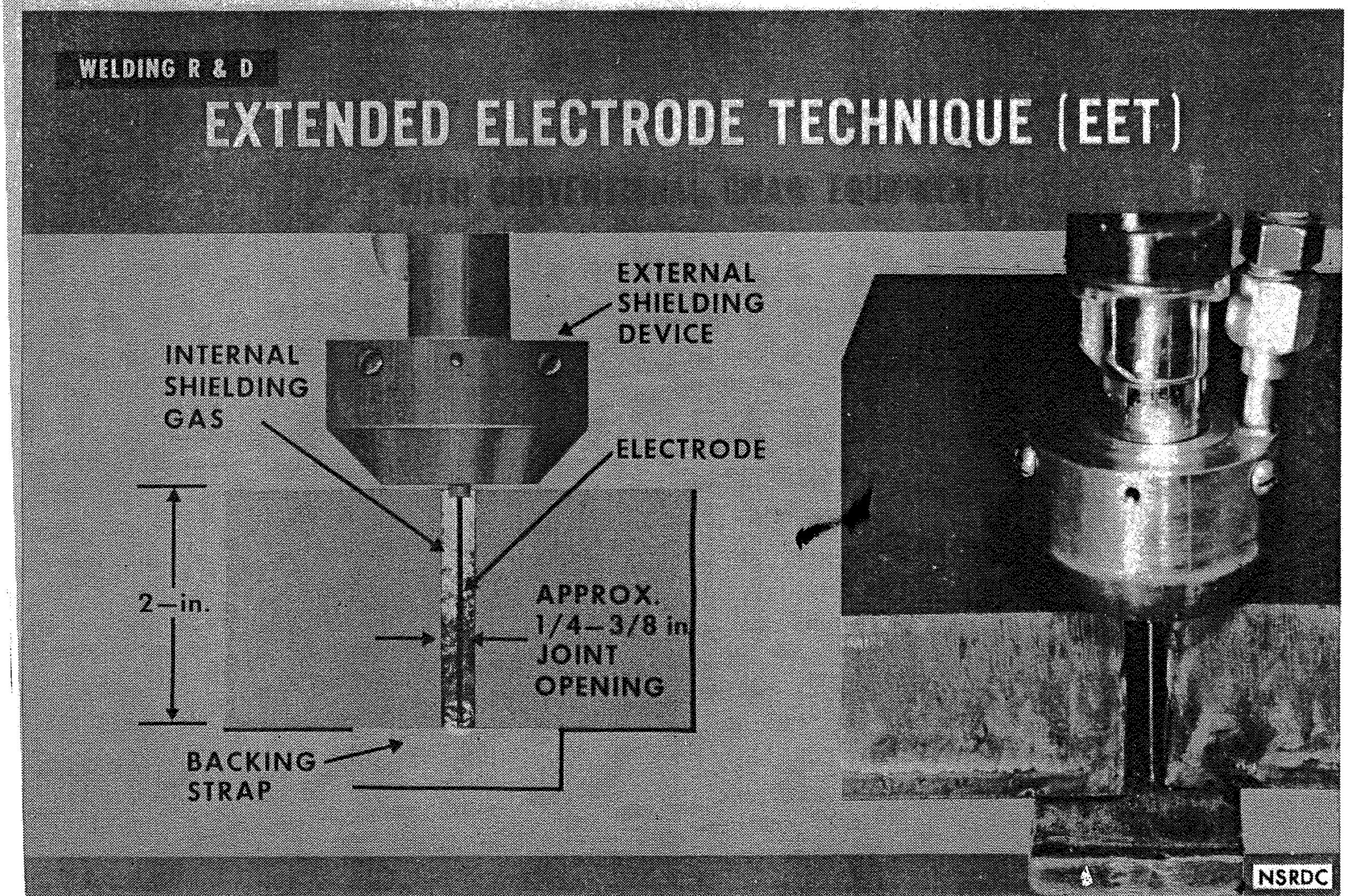
WELDING R & D
EXTENDED ELECTRODE TECHNIQUE (EET)
EXTERNAL SHIELDING DEVICE
INTERNAL SHIELDING GAS
ELECTRODE
2—in.
APPROX. 1/4—3/8 in JOINT OPENING
BACKING STRAP
NSRDC

Figure 2

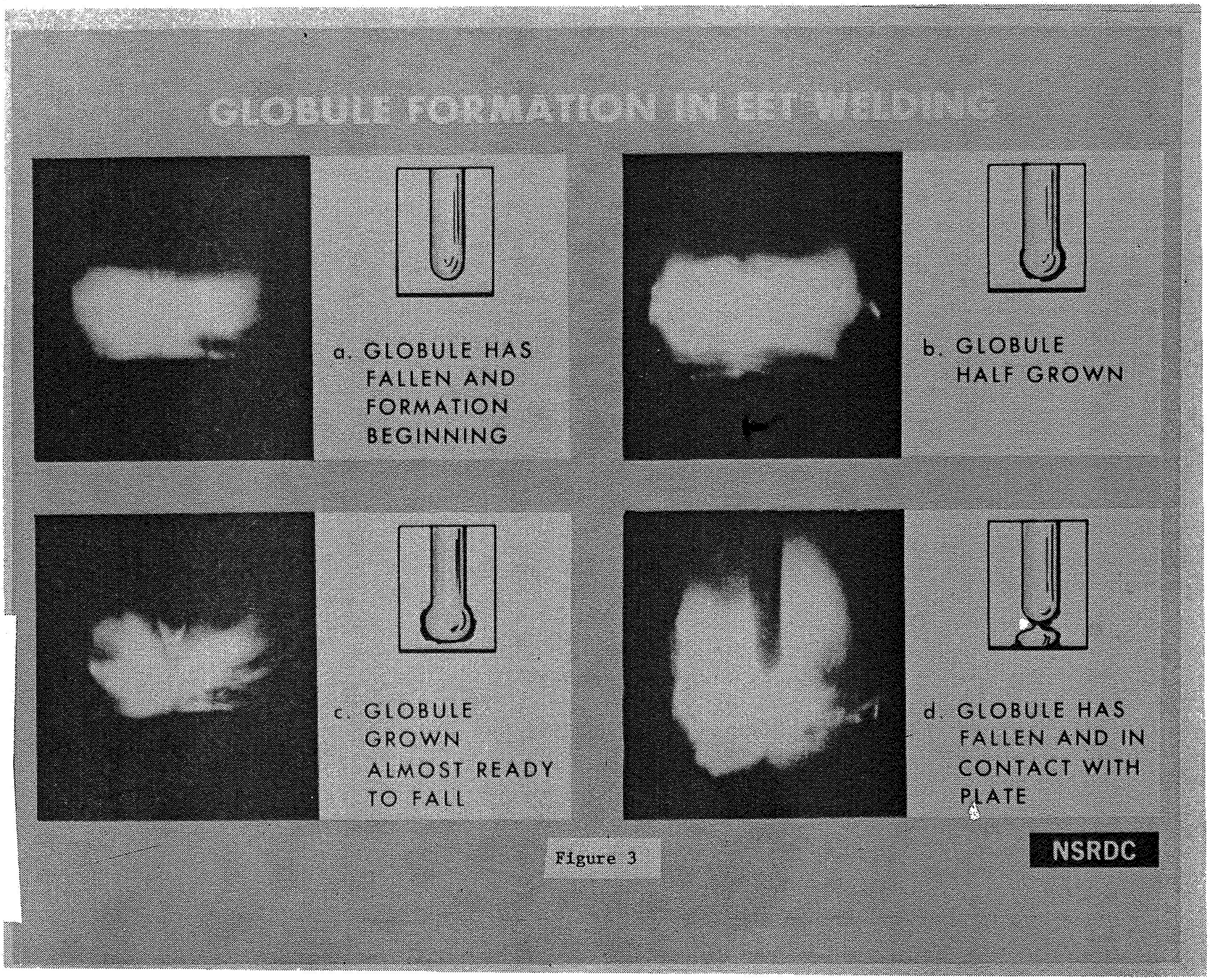
GLOBULE FORMATION IN
a. GLOBULE HAS FALLEN AND FORMATION BEGINNING
b. GLOBULE HALF GROWN
c. GLOBULE GROWN ALMOST READY TO FALL
d. GLOBULE HAS FALLEN AND IN CONTACT WITH PLATE
NSRDC

Figure 3

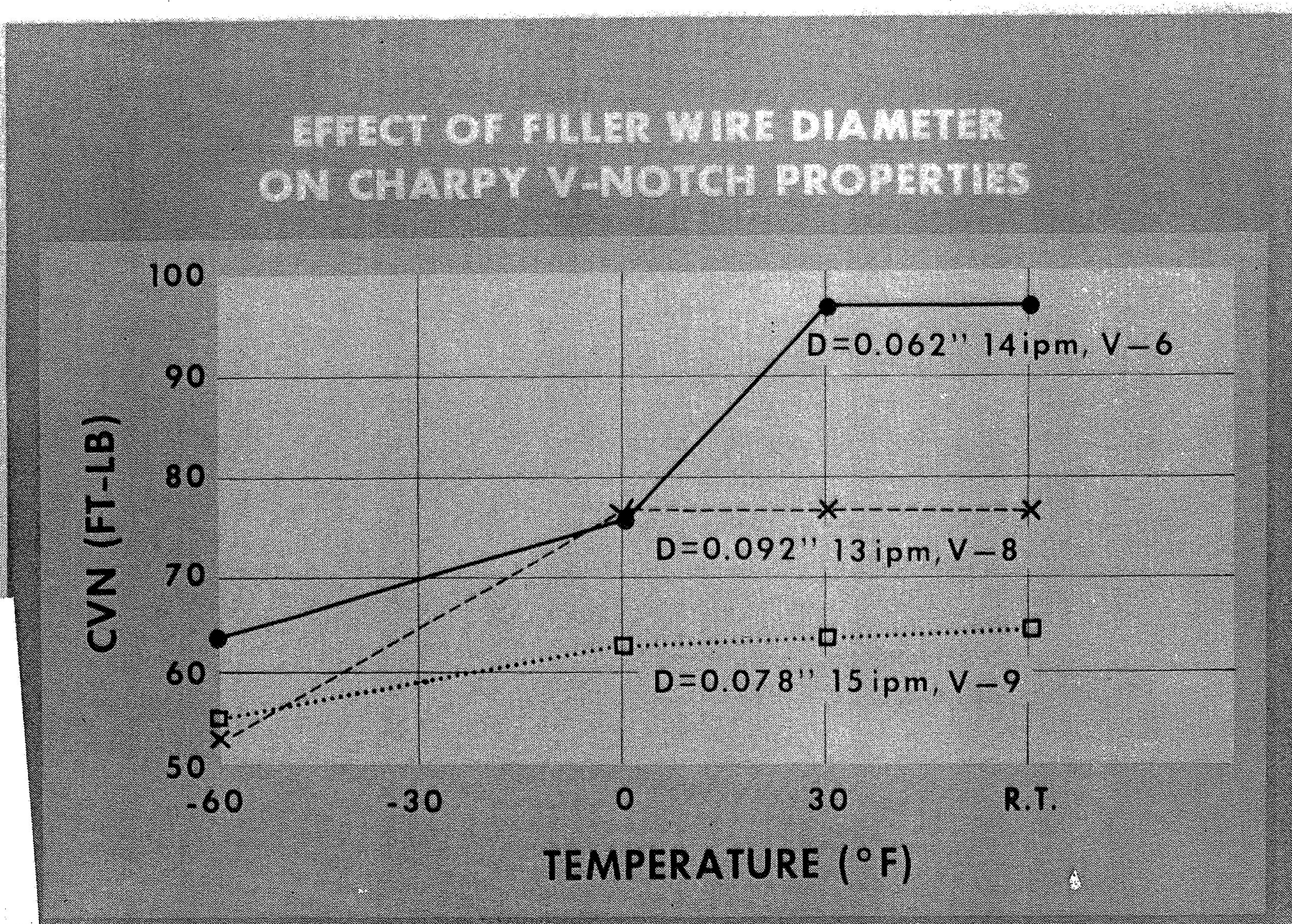
EFFECT OF FILLER WIRE DIAMETER
ON CHARPY V-NOTCH PROPERTIES
CVN (FT-LB)
100
90
80
70
60
50
-60
-30
0
30
R.T.
TEMPERATURE (°F)
D=0.062'' 14 ipm, V—6
D=0.092'' 13 ipm, V—8
D=0.078'' 15 ipm, V—9
NSRDC

Figure 4

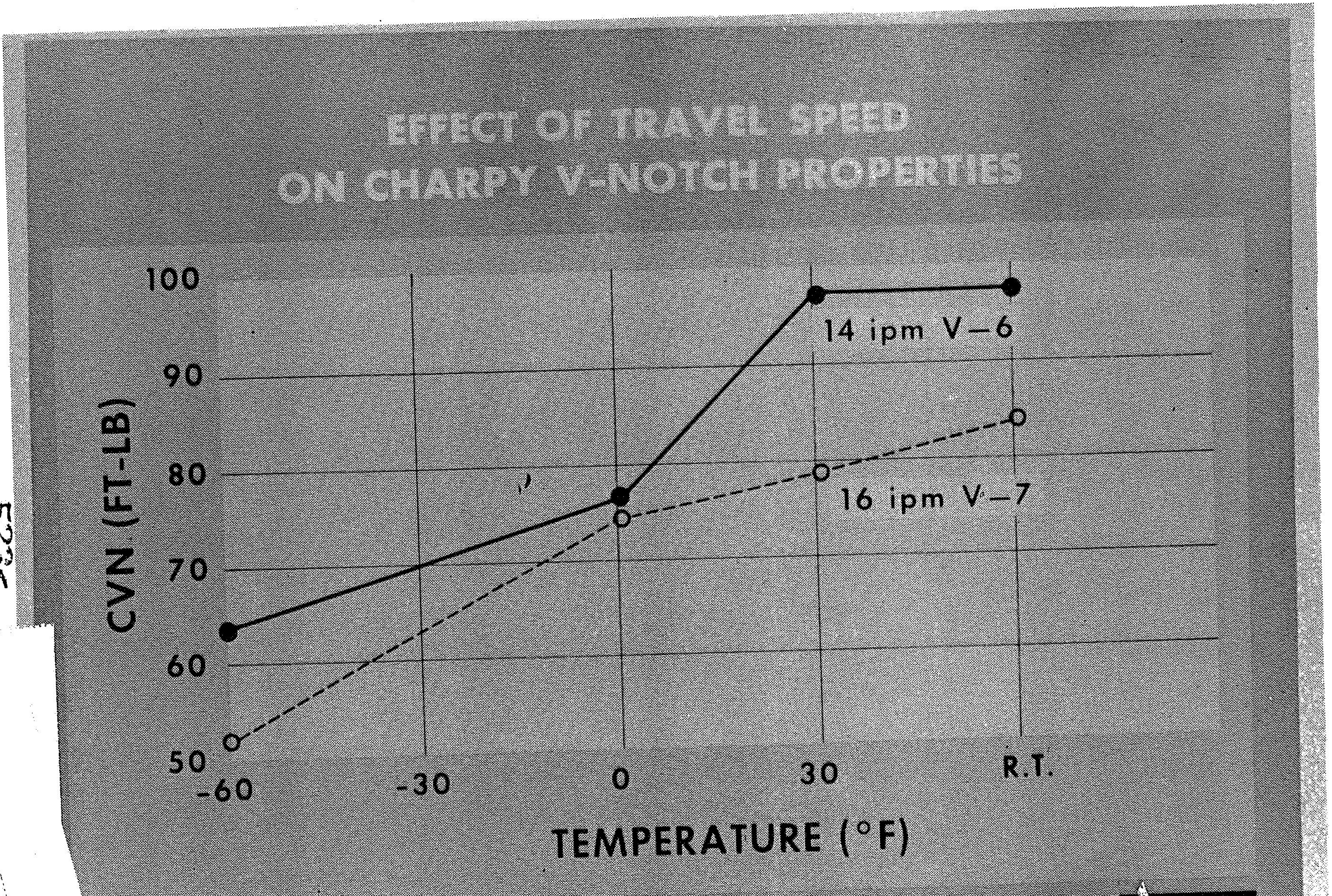
EFFECT OF TRAVEL SPEED
ON CHARPY V-NOTCH PROPERTIES
CVN (FT-LB)
100
90
80
70
60
50
-60
-30
0
30
R.T.
TEMPERATURE (°F)
14 ipm V—6
16 ipm V—7
NSRDC

Figure 5

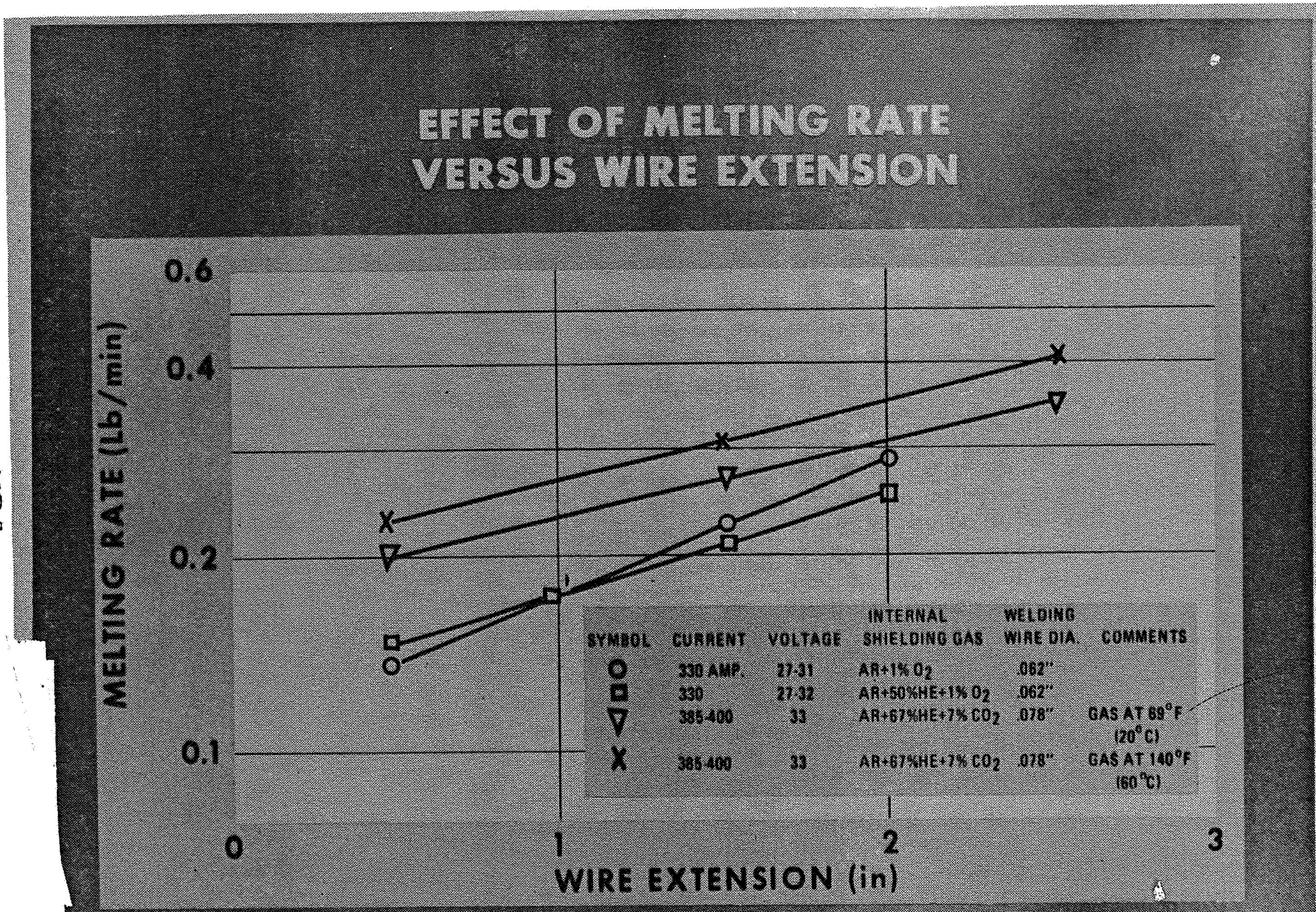
EFFECT OF MELTING RATE
VERSUS WIRE EXTENSION
MELTING RATE (Lb/min)
0.6
0.4
0.2
0.1
0
1
2
3
WIRE EXTENSION (in)
INTERNAL
WELDING
SYMBOL CURRENT VOLTAGE SHIELDING GAS WIRE DIA. COMMENTS
○ 330 AMP. 27-31 AR+1% O2 .062"
□ 330 27-32 AR+50%HE+1% O2 .062"
▽ 385-400 33 AR+67%HE+7% CO2 .078" GAS AT 69°F (20°C)
X 385-400 33 AR+67%HE+7% CO2 .078" GAS AT 140°F (60°C)
NSRDC

Figure 6

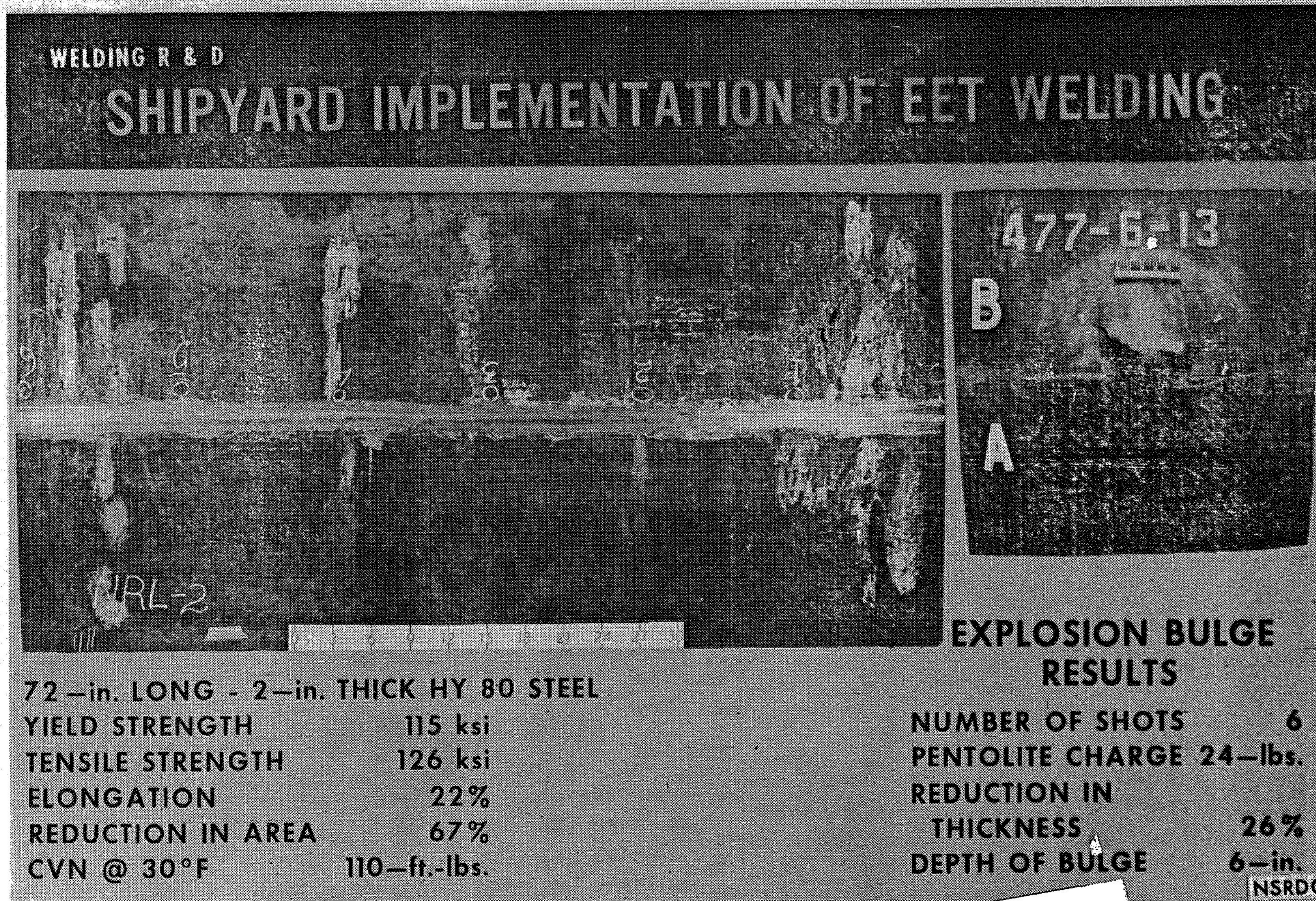
WELDING R & D
SHIPYARD IMPLEMENTATION OF EET WELDING
477-6-13
B
A
NRL-2
72—in. LONG - 2—in. THICK HY 80 STEEL
YIELD STRENGTH 115 ksi
TENSILE STRENGTH 126 ksi
ELONGATION 22%
REDUCTION IN AREA 67%
CVN @ 30°F 110—ft.-lbs.
EXPLOSION BULGE RESULTS
NUMBER OF SHOTS 6
PENTOLITE CHARGE 24—lbs.
REDUCTION IN THICKNESS 26%
DEPTH OF BULGE 6—in.
NSRDC

Figure 7

FIG. 8 TYPICAL HARDNESS VALUES OF EXTENDED ELECTRODE TECHNIQUE WELDS

(VALUES IN R_c)

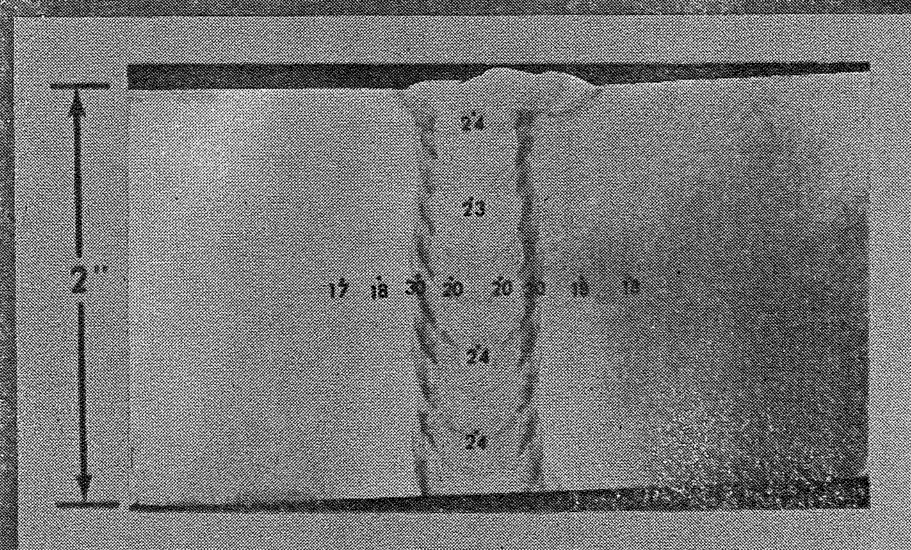

Figure 8